NASA Innovative Advanced Concepts

Biomaterials out of thin air: in situ, on-demand printing of advanced biocomposites

Completed Technology Project (2013 - 2014)

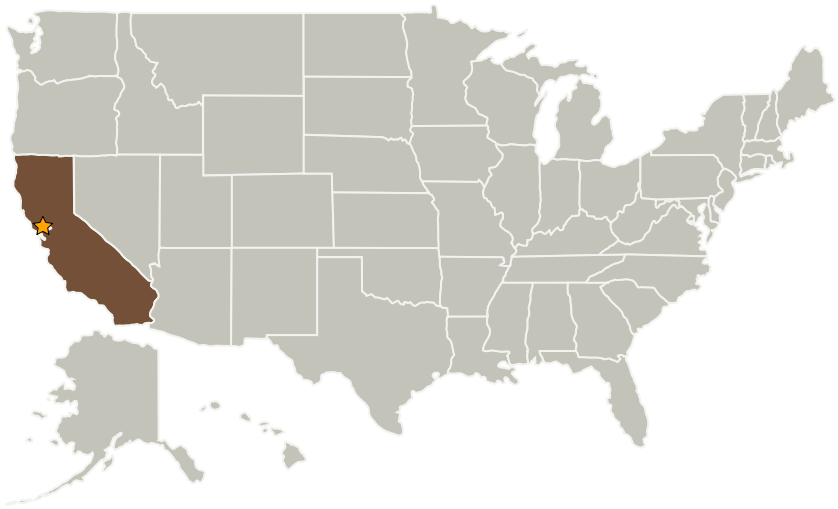
Project Introduction

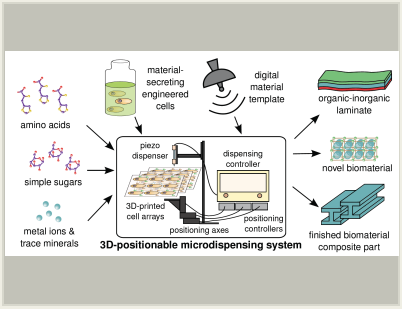
The concept is that a 3D array of bioengineered living cells deposits materials, both biological and inorganic, that are bound into nonliving, microstructured finished products. Imagine being able to print anything from tools and composite building materials to food and human tissues. Imagine being on Mars with the ability to replace any broken part, whether it's a part of your spacesuit, your habitat, or your own body. We propose a technique that would allow just that. By printing 3D arrays of cells engineered to secrete the necessary materials, the abundant in situ resources of atmosphere and regolith become organic, inorganic, or organic-inorganic composite materials. Such materials include novel, biologically derived materials not previously possible to fabricate.

Anticipated Benefits

Benefits of this concept include: drastically reduceing upmass requirements of many current space missions, greatly multiplying the potential of off-planet in situ resource utilization, enabling a new class of space missions currently precluded by material transport needs, and vast potential for exploration of novel, synthetic biomaterials and biocomposites.

Primary U.S. Work Locations and Key Partners





Concept Diagram

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Organizations Performing Work	Role	Type	Location
★Ames Research Center(ARC)	Lead Organization	NASA Center	Moffett Field, California
Stanford University(Stanford)	Supporting Organization	Academia	Stanford, California
University of California-Santa Cruz	Supporting Organization	Academia	Santa Cruz, California

Primary U.S. Work Locations
California

Project Transitions

August 2013: Project Start

Organizational Responsibility

Responsible Mission Directorate:

Space Technology Mission Directorate (STMD)

Lead Center / Facility:

Ames Research Center (ARC)

Responsible Program:

NASA Innovative Advanced Concepts

Project Management

Program Director:

Jason E Derleth

Program Manager:

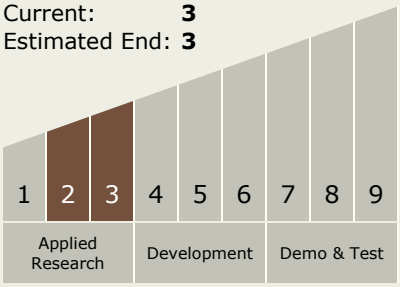
Eric A Eberly

Principal Investigator:

Lynn J Rothschild

Technology Maturity (TRL)

Start: **2**
Current: **3**
Estimated End: **3**



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May 2014: Closed out

Closeout Summary: The mission benefit analyses as described in our Phase I p roposal (Objective #2, Section 6) are complete and contained in this report. As was appropriate for the information we had prior to the completion of the proof of concept, we focused on the benefits due to material subsitution and in situ re source utilization. These calculations alone show that our technology can save h undreds of kilograms of upmass for a potential human habit construction missio n (a net mass savings of approximately one third per habitat module without IS RU, or mass savings including the full 240 kg per module if all materials are deri ved from ISRU). We have shown that continued advancement of this technology concept for use in a space mission environment is justified. We completed the pr oof of concept described in our Phase I proposal (Objective #1, Section 7), a tw omaterial array of non-structural proteins. We created an implementation of eac h step in our technology concept (Figure 7.1) and demonstrated its critical functi onality (Table 7.2). Our current host cells are S. cerevisiae, a yeast, genetically engineered to secrete our target materials, fluorescent-tagged proteins, when e xposed to galactose. Our current print medium and substrate are a glucose-cont aining alginate medium deposited onto a calcium-and galactose-containing agar surface. The calcium gels the alginate, and the introduction of galactose when th e cells contact the substrate triggers the material secretion. This way, the act of printing is combined with the act of creating a physical support for the cells and providing the material production stimulus, greatly simplifying the end-to-end-p rocess. The biological chassis and printing hardware we created as part of this w ork can be re-used for future work by inserting a material coding region upstrea m of the fluorescent tag. Overall, we showed that our technology concept is sou nd. Our survey of future development pathways (Objective #3, Section 8) prove d extremely informative in light of the lessons learned from our proof of concept work and mission scenario analyses. For example, we were able for the first tim e to distinguish between the levels of functionality provided by production of str uctural proteins, other polymers such as polysaccharides, and true organic-inorg anic composites such as bone and mineralized shell. We were also able to surve y the state of knowledge of the precise mechanisms involved in the formation of both non-protein-based structural materials, such as chitin and cellulose, and th e inorganic phase of biominerals, and quantify our previously qualitative estimat es of our technology concept's reliance on advances in other fields. Both of thes e analyses represent significant advances in formulating specific applications for our technology concept. For Objective #4 (Section 9), we surveyed potential co llaborations with other projects and synergies with enabling technologies that ar e developing, including labs at Stanford University and Drexel University, Organ ovo, and Autodesk. Collaboration with tissue engineers at Organovo would allow our technology to develop in parallel with tissue printing technology, and collabo ration with Autodesk would speed the development of software to translate stan dard 3D model file formats into commands usable by the bioprinter. Finally, we have been in touch with the team behind the 2013 NIAC Phase II 'Super Ball Bot -Structures for Planetary Landing and Exploration' and are planning to develop o ur biomaterial printing technology with the goal of enabling tensegrity-based rov ers such as theirs to use lighter, more robust materials. A smooth transition fro m TRL 2 to TRL 3 assumes that the implementations of the technology concept which demonstrate critical functionality are also pathways for future developmen t; while this is the case for most hardware or software projects, the multidiscipli nary nature of our project, particularly the biological aspect of it, means that thi s is not always true. The most clear example of this in our Phase I work is the fa ct that our polyhistidine tag material binding method worked sufficiently well for

Technology Areas

Primary:

- TX12 Materials, Structures, Mechanical Systems, and Manufacturing
  - TX12.1 Materials
    - TX12.1.1 Lightweight Structural Materials

Target Destinations

Earth, Foundational Knowledge

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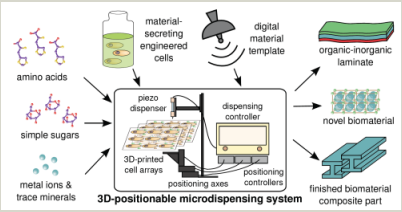
Images



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Concept Diagram
(https://techport.nasa.gov/image/102281)